The Embodied Greenhouse Gas Emissions of Carbon Dioxide Refrigerant (R-744) as an Adjustment to Global Warming Potential

by

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Life Cycle Climate Performance (LCCP) -What Information Do You Need?

- Pre-Use: Embodied Greenhouse Gas Emissions
  - **Embodied Energy Emissions**: From the energy required to produce and transport refrigerant and parts
  - **Fugitive Emissions**: refrigerant or byproduct from plant and transportation
- During Use- (TEWI)
- Post-Use

Finding the Pieces of the LCCP Puzzle

- Many Breakthroughs have been made (examples)
  - **Gamlen et al. (1986) Fugitive emissions of CFC-12**
  - **Campbell and McCulloch (1998) embodied energy emissions of CFC-12 (R-12), HCFC-22 (R-22), HFC-134a (R-134a), ammonia, isobutane, and cyclopentane**
  - **A.D. Little (2002) Fugitive Emissions of HCFC-22, HFC-134a**
  - **Krieger et al. (2004) Embodied energy and fugitive emissions of HFC-152a**

Finding the Pieces of the LCCP Puzzle

(Continued)

Refrigerant	Embodied Energy, kgCO2/kgR	Fugitive Emissions	Atmospheric Life	100 year GWP	Adjusted GWP
CFC-12	3	265	100 years	10600	10868
HCFC-22	3	390	11.9 years	1700	2093
HFC-134a	5.2	4.2	13.8 years	1300	1309.4
HFC-152a	1.9	0.3	1.4 years	140	122.2
CO2	?????	?????	>50 years	1	?????

- Embodied Energy values from Campbell and McCulloch, 1998 and Krieger, Bateman, and Sylvester 2004
- Fugitive Emission Values from Gamlen et.al. 1986 and Arthur D. Little, 2002
- Atmospheric Live from 2002 RTOC Report
- 100 Year GWP values from IPCC 2001

And Now For Carbon Dioxide!

- Embodied Energy Emissions
  - Production
  - Transport
- Fugitive Emissions

Production Energy

- Depends on pressure and purity of feedgas
  - Well Sources- High P&P
    - Base GWP=1
  - Scavanged Sources- Medium P&P
    - Ammonia, Ethanol, Oil Refineries, Gypsum
    - Base GWP=0
  - Combustion Sources- Very Low P&P
    - Not used for refrigerant- inefficient and impure
    - Base GWP=1

Looking at Main-Stream Market

- Directory of Limiting Characteristics and Quality Verification Levels

Limiting Characteristics	Quality Verification Levels					
	E	F	G	H	I	J
CO2, % min	99.0	99.5	99.5	99.8	99.8	Dry ice only- same as I, increased non-volatile residues
Water, ppm	200	120	32	32	20	
Dew Point, °C	-35.6	-40	-51	-51	-55	

  - Compressed Gas Association's Handbook of Compressed Gases

- SAE Proposed Purity Specification= Grade F or Better
- All production from contacted companies adheres to this standard
  - below this is corrosive to expensive equipment

Production Energy Calculated

- 4 Largest Producers= 80% of Market
- Purification/Liquefaction powered by electricity
  - Reported 39-77 kWh/tonne (35-70 kWh/ton) for well sources
  - Reported 165-248 kWh per tonne (150-225 kWh/ton) for scavenged sources
- 0.69 kg CO2 emitted for every kWh *distributed*
  - 0.63 kg emitted per kWh *produced* (eGRID 2002)
  - transmission inefficiency of 9% (EIA 2002)

Production Energy Calculated
(continued)

- Well Sources
  - lower bound 0.027 kg CO_2 per kg R-744 produced
  - upper bound 0.054 kg CO_2 per kg R-744 produced
- Scavenged Sources
  - lower bound 0.114 kg CO_2 per kg R-744 produced
  - upper bound 0.171 kg CO_2 per kg R-744 produced

Transportation Energy

- Depends more on distances (distribution of factories and customers) than on type of transport.
- Two producers (28% of market) reported
- Two forms of transport
  - Truck 75%
  - Rail 25%

Transportation Energy Calculated

- Trucks
  - Companies manage their own fleets
  - Reported 5.8 and 7.5 liters/tonne (1.4 and 1.8 gallons/ton)
- Rail
  - Reported average rail distances of 805 and 1770 km (500 and 1100 miles)
  - Average rail efficiency 0.0025 gal/ton-mile (Association of American Railroads, 2002)
  - 5.22 and 11.47 liters/tonne (1.25 and 2.75 gal/ton)

Transportation Energy Calculated
(continued)

- Weighted both companies diesel use for 75% trucking 25% rail
  - Company 1= 5.66 L/tonne (1.36 gal/ton)
  - Company 2= 8.49 L/tonne (2.03 gal/ton)
- 1 liter diesel= 2.68 kg CO_2 emitted (1 gal= 22.38 lbs) (EIA, 2003)
- Lower bound 0.015kg CO_2 per kg R-744 Transported
- Upper bound 0.023 kg CO_2 per kg R-744 Transported

Fugitive Emissions

- CO_2 production has no byproducts
- Just look at CO_2 leakage
- Producers say
  - Plant 1-2%
  - Transportation 3-7%
- Totals 4-9%, or 0.04-0.09 kg CO_2 emitted per kg R-744 produced and delivered.


26080
48860
NATIONAL CO2
LIQUID CARBONATION SERVICE
7848
TK230
2187
CAUTION
WIDE TURNS
THIS VEHICLE STOPS AT ALL RAILROAD CROSSINGS
T-55470
CHOCK

Combined Embodied Energy and Fugitive Emissions Lead to Adjusted GWP

CO_2 Source	Content GWP (100 year)	kg. CO_2 emitted per kg. R-744 produced		kg. CO_2/ kg R-744 transported		fugitive emissions kg CO_2/ kg R-744		Total kg CO_2/kg produced and trans-ported + GWP	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Scavenged	0	0.114	0.171	0.015	0.023	0	0	0.129	0.194
Wells	1	0.027	0.054	0.015	0.023	0.040	0.090	1.082	1.167
Weighted (28% Well, 72% Scavenged)	0.28	0.090	0.138	0.015	0.023	0.029	0.065	0.4	0.5

- **Entire Range is 0.129 to 1.167 kg CO_2 per kg CO_2**
- **This is Adjusted GWP!!**
- **Weighted Range is 0.4 to 0.5 GWP**

Information for Refrigerant Comparison

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HFC-152a	1.9	0.3	1.4 years	140	122.2
CO2	0.04 to 0.19	0 to 0.09	>50 years	0 to 1	0.13 to 1.17

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Additional Information

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